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IMPORTANT TOOLS AND PARAMETERS OF FRICTION STIR WELDING

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ABSTRACT

The friction stir welding (FSW) process is a recent solid-state joining process to produce the permanent joint of two dissimilar metals. In this paper, the study of the effects of tool rotation speed and welding speed on the tensile strength, Microstructure, Micro hardness properties during friction stir welding process has been done. From the literature, it is understood that tool rotation speed and welding speed play an important role on the mechanical properties and weld quality. Important results reported by various authors are critically reviewed.

KEYWORDS: Friction Stir Welding, Mechanical Properties, Welds Quality, Axial Force & Welding Speed

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Original Article

INTRODUCTION

Friction Stir Welding (FSW) is a solid state joining technique invented by The Welding Institute (TWI), Cambridge, UK, in 1991. The FSW process uses a, non-consumable cylindrical tool consisting of a shoulder, and a smaller diameter profiled pin, protruding from the tool shoulder. The rotating tool is slowly plunged nto rigidly clamped work pieces. The shoulder makes intimate contact with the work piece surfaces. The pin is completely embedded within the through-thickness of the work pieces. However, it does not touch the bottom of the work pieces [1,2]. It is observed from literature that friction stir welding is more advantageous such as good weld appearance, improve strength, ductility, resistance to corrosion, fine grain structure and welded surface as compare to other welding techniques. FSW machine consist of non-consumable rotating tool with probe or pin which is forced down into the joint line where the frictional heating is sufficient to raise the temperature of the material to the range where it is plastically deformed. Tool rotational speed, welding speed and tilt angle are the important influencing process parameters on tensile strength and hardness. The traversing force and side force are not considered as process parameters and only used for monitoring the process. Friction stir welding parameters have been selected based on acceptable mechanical, micro structural, fatigue and corrosion properties requirement to obtain efficient, defect free friction stir welded joints [3].

The history of joining metals goes back several millennia, with the earliest examples of welding from the Bronze Age and the Iron Age. From that time the process of welding gone through several modifications, world wars caused a major surge in the use of welding processes, with the various military powers attempting to determine which of the several new welding processes would be best. Many sophisticated welding methods for different alloys of variety applications are available now. Friction stir welding (FSW) is a solid state process forjoiningmaterials, especially dissimilar materials, which involves generation of heat by the conversion of mechanical energy into thermal energy at the interface of the work pieces without using electrical energy or heat from other sources during rotation under pressure [4]. As a high-quality, precise, high-efficiency, energy-saving and environmental friendly technique, FSW has been widely used in the aerospace, shipbuilding, automobile industries and in many applications

of commercial importance. Some of the advantages over the conventional welding techniques are very low distortion, no fumes, porosity or spatter, no consumables, no special surface treatment and no shielding gas requirements [5].

DEVELOPMENT OF FRICTION STIR WELDING

The Friction Stir Welding (FSW) process was invented in 1991 by The Welding Institute (TWI) at Cambridge, in United Kingdom. It was further developed and was got patented by the Welding Institute. The first built and commercially available friction stir welding machines were produced by ESAB1 Welding and Cutting Products at their equipment manufacturing plant in Laxa, Sweden. The development of this process was a significant change from the conventional rotary motion and linear reciprocating friction welding processes. It provided a great deal of flexibility within the friction welding process group [6].

Since 1995 in Europe, Friction Stir Welding has been used in production applications. The first applications involved welding of extrusions to form paneling for marine applications. Since then, the process has been commercialized in many other applications, including rail car, automotive, aerospace, heavy truck, medical applications, etc. Today, the process is being transitioned into fabrication of complex assemblies, yielding significant quality and cost improvements. As the process is maturing, designers are taking advantage of the process, by designing the product specifically for the FSW process. The Friction Stir Welding is apparently quite new welding process as shown in Figure 1 and is a good process for particularly welding aluminum parts. The conventional rotary friction welding process requires at least one of the parts being joined to be rotated and has the practical limitation of joining regular shaped components, preferably circular in cross-section and limited in their length. Short tubes or round bars of the same diameter are a good example[7].

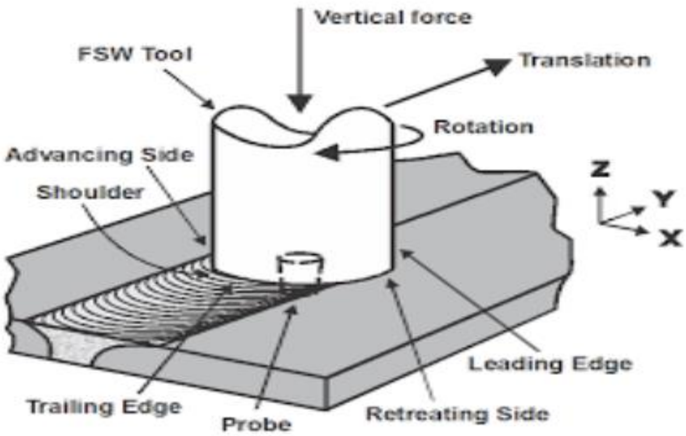


Figure 1: Mechanism of Friction Stir Welding.

WELDING TOOLS AND PARAMETERS

There is a consensus that the most mportant welding parameter is the rotation speed, but that the transverse speed and plunge depth are also very significant. Rotation speed determines the heat input and temperature as well as the shear experienced by the FSW welds. Consequently, it influences the microstructure and mechanical properties of the FSW welds. Other welding parameters include tilt angle, spindle power, torque, Z force, as well as the distance between the FSW weld and the side of the plate [8].

Many factors affect the process of FSW. Colligan and Mishra (2008) developed a conceptual model of the influence of different welding parameters on the FSW process. Figure (2) shows the model of the relationships between different

welding parameters and their effects [9].

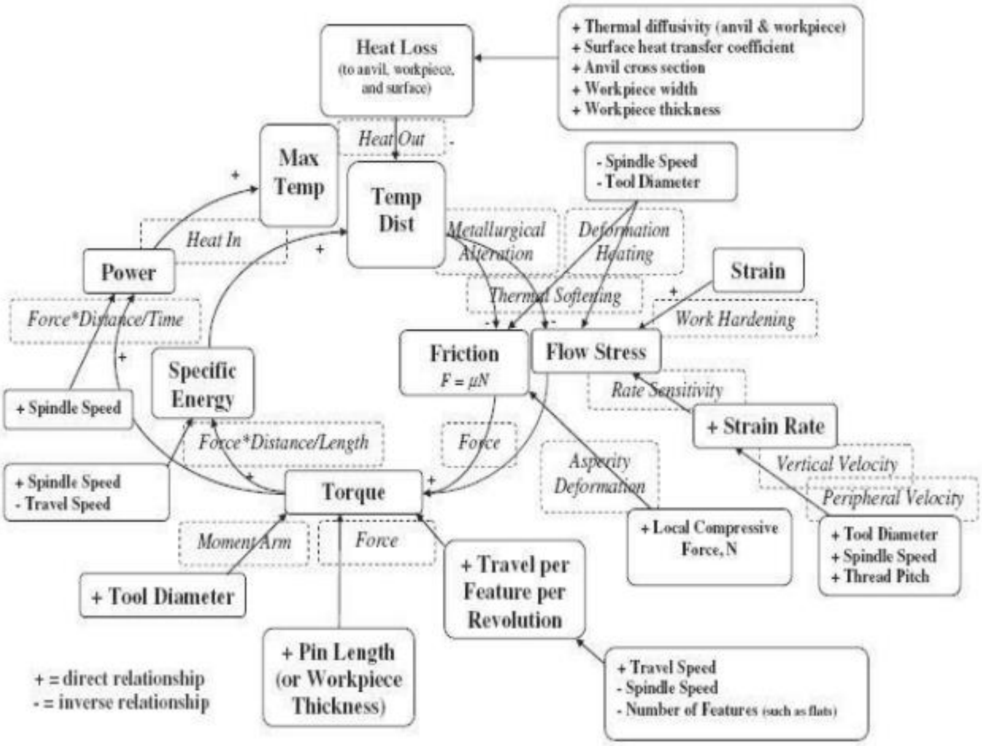


Figure 2: Conceptual Model of the Relationships between Welding Parameters and their Effects

When using FSW, the following parameters must be controlled: down force, welding speed, the rotation speed of the welding tool and tilting angle. The main process parameters and there effects in friction stir welding are given below Table 1 (FSW-Technical- Handbook) [10].

Table 1: Main‘Process‘Parameters in‘Friction‘Stir‘Welding

Parameter	Effects
Rotation speed	Frictional heat, “stirring”, oxide layer breaking and mixing of material
Tilting angle	The appearance of the weld, thinning
Welding speed	Appearance, heat control.
Down force	Frictional heat, maintaining contact conditions

Tool Design

Advanced Friction Stir Welding and processing tools by Mega Stir shown. The design of the tool [6] is a critical factor, as a good tool can improve both the quality of the weld and the maximal possible welding speed.

It is desirable that the tool material be sufficiently strong, tough, and hard wearing at the welding temperature. Further, it should have a good oxidation resistance and a low thermal conductivity to minimise heat loss and thermal damage to the machinery further up the drive train. Hot-worked tool steel such as AISI H13 has proven perfectly acceptable for welding aluminium alloys within thickness ranges of 0.5–50 mm [11] but more advanced tool materials are necessary for more demanding applications such as highly abrasive metal matrix composites [8] or higher-melting-point materials such as steel or titanium.

Improvements in tool design have been shown to cause substantial mprovements in productivity and quality. TWI

has developed tools specifically designed to increase the penetration depth and thus increasing the plate thicknesses that can be successfully welded. An example is the "whorl" design that uses a tapered pin with re-entrant features or a variable-pitch thread to improve the downwards flow of material. Additional designs include the Triflute and Trivex series. The Triflute design has a complex system of three tapering, threaded re-entrant flutes that appear to increase material movement around the tool. The Trivex tools use a simpler, non-cylindrical, pin and have been found to reduce the forces acting on the tool during welding Figure (3) [12].

Figure 3: Advanced Friction Stir Welding and Processing Tools by MegaStir shown Upside Down.

The majority of tools have a concave shoulder profile, which acts as an escape volume for the material displaced by the pin, prevents material from extruding out of the sides of the shoulder and maintains downwards pressure and hence good forging of the material behind the tool. The Triflute tool uses an alternative system with a series of concentric grooves machined nto the surface, which are intended to produce additional movement of material in the upper layers of the weld [13].

Widespread commercial applications of friction stir welding process for steels and other hard alloys such as titanium alloys will require the development of cost-effective and durable tools.[9] Material selection, design and cost are important considerations in the search for commercially useful tools for the welding of hard materials. Work is continuing to better understand the effects of tool material's composition, structure, properties and geometry on their performance, durability and cost [14].

Tool Rotation and Traverse Speeds

There are two tool speeds to be considered in friction-stir welding; how fast the tool rotates and how quickly it traverses along the interface. These two parameters have considerable mportance and must be chosen with care to ensure a successful and efficient welding cycle. The relationship between the rotation speed, the welding speed and the heat input during welding is complex, but in general, it can be said that increasing the rotation speed or decreasing the traverse speed will result in a hotter weld. In order to produce a successful weld, it is necessary that the material surrounding the tool is hot enough to enable the extensive plastic flow required and minimize the forces acting on the tool. If the material is too cold, then voids or other flaws may be present in the stir zone and in extreme cases the tool may break [15].

Excessively high heat nput, on the other hand, may be detrimental to the final properties of the weld. Theoretically, this could even result in defects due to the liquation of low-melting-point phases (similar to liquation cracking in fusion welds). These competing demands lead onto the concept of a "processing window": the range of processing parameters viz.

tool rotation and traverse speed, that will produce a good quality weld.[10] Within this window the resulting weld will have a sufficiently high heat input to ensure adequate material plasticity but not so high that the weld properties are excessively deteriorated [16].

Tool Tilt and Plunge Depth

The plunge depth is defined as the depth of the lowest point of the shoulder below the surface of the welded plate and has been found to be a critical parameter for ensuring weld quality. [12] Plunging the shoulder below the plate surface increases the pressure below the tool and helps ensure adequate forging of the material at the rear of the tool. Tilting the tool by 2–4 degrees, such that the rear of the tool is lower than the front, has been found to assist this forging process. The plunge depth needs to be correctly set, both to ensure the necessary downward pressure is achieved and to ensure that the tool fully penetrates the weld. Given the high loads required, the welding machine may deflect and so reduce the plunge depth compared to the nominal setting, which may result in flaws in the weld. On the other hand, an excessive plunge depth may result in the pin rubbing on the backing plate surface or a significant under match of the weld thickness compared to the base material. Variable-load welders have been developed to automatically compensate for changes in the tool displacement, while TWI have demonstrated a roller system that maintains the tool position above the weld plate Figure (4) [17].

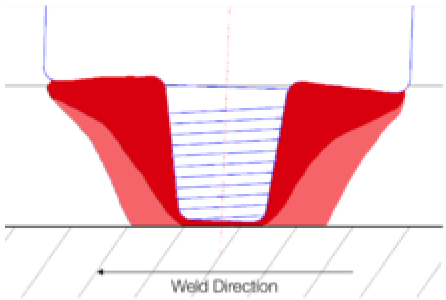


Figure 4: A drawing showing the Plunge Depth and Tilt of the Tool. The Tool is Moving to the Left.

PRINCIPLE OF OPERATION

In Friction Stir Welding, a cylindrical shouldered tool with a profiled probe is rotated and slowly plunged into the joint line between two pieces of sheet or plate material, which are butted together. The parts have to be firmly clamped onto the worktable n a manner that prevents the joint faces from being forced apart. Frictional heat is generated between the wear resistant welding tool and the material of the work piece as shown in Figure 5 (b). This heat causes the latter to soften without reaching the melting point and allows passing of the tool along the weld line as shown n Figure 5 (c). The plasticized material is transferred from the leading edge of the tool to the trailing edge of the tool probe and is forged by the ntimate contact of the tool shoulder and the pin profile. t leaves a solid phase bond between the two pieces [18].

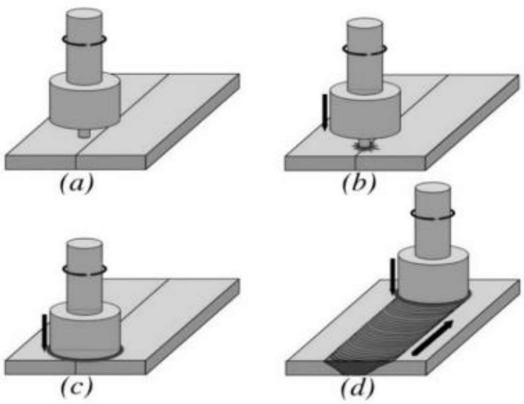
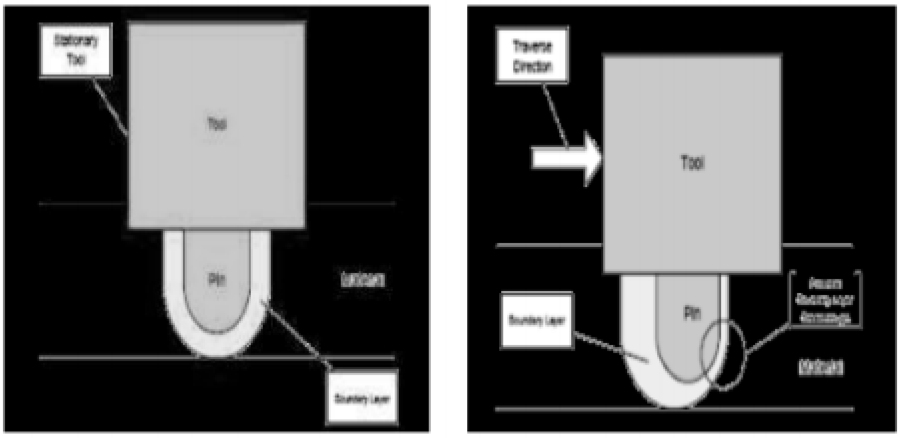


Figure 5: FSW Working Processes: (a) Starting position, (b). Start of joining, (c). Insert joining tool and (d). Joining

Tool Rotation and Traverse Speeds

There are two tool speeds to be considered in friction-stir welding; how fast the tool rotates and how quickly it traverses the interface. These two parameters have considerable mportance and must be chosen with care to ensure a successful and efficient welding cycle [19-20]. The relationship between the welding speeds and the heat input during welding is complex but, in general, it can be said that increasing the rotation speed or decreasing the traverse speed will result in a hotter weld as shown in Figs. 6 (a) and 6 (b). Another end of the scale excessively high heat input may be detrimental to the final properties of the weld. Theoretically, this could even result in defects due to the liquation of lowmelting-point phases (similar to liquation cracking in fusion welds). These competing demands lead onto the concept of a processing window: the range of processing parameters that will produce a good quality weld. Within this window the resulting weld will have a sufficiently high heat input to ensure adequate material plasticity but not so high that the weld properties are excessively reduced [21-22].



(a) (b)

Figure 6: (a) Tool Rotation and (b) Transverse Speed.

Tool Tilt and Plunge Depth

The plunge depth is defined as the depth of the lowest point of the shoulder below the surface of the welded plate and has been found to be a critical parameter for ensuring weld quality. Plunging the shoulder below the plate surface ncreases the pressure below the tool and helps ensure adequate forging of the material at the rear of the tool [22-24]. Tilting the tool by

2-4 degrees, such that the rear of the tool is lower than the front, has been found to assist this forging process. The plunge depth needs to be correctly set, both to ensure the necessary downward pressure is achieved and to ensure that the tool fully penetrates the weld. Given the high loads required the welding machine may deflect and so reduce the plunge depth compared to the nominal setting, which may result in flaws in the weld [25-26]. On the other hand, an excessive plunge depth may result in the pin rubbing on the backing plate surface or a significant under match of the weld thickness compared to the base material. Variable load welders have been developed to automatically compensate for changes in the tool displacement while The Welding nstitute (TWI) has demonstrated a roller system that maintains the tool position above the weld plate [27-28].

CONCLUSIONS

From literature review, it is observed that the friction stir welding process offers many advantages over fusion welding processes for joining Aluminium alloys. However, most of the reported research papers are focusing on FSW of wrought Aluminium alloys. Very few papers are found related to FSW of cast Aluminium alloys. Though this process shows more promise over fusion welding processes to join cast Aluminium alloys, the usefulness of this process is not yet explored by the researchers. Hence, many investigations have been carried out to make a systematic study to understand the effect of FSW process parameters on mechanical and metallurgical properties of cast Al alloys.

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